Case Study.

Boeing Catches a Lift with High Performance Computing

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Boeing Catches a Lift with High Performance Computing

Through the Department of Energy's Innovative and Novel Computational Impact on Theory and Experiment (INCITE) competition, Boeing R&D researchers recently won a multi-issue, multi-industry, international competition for a grant to use the powerful supercomputers at Oak Ridge National Laboratory (ORNL), bolstering their access to Boeing's own in-house high performance computing (HPC) capabilities. Access to the lab's leadership class systems allows Boeing scientists and researchers to tackle problems that are beyond the reach of the company's in-house supercomputers and HPC clusters. Because ORNL constantly upgrades its supercomputer capabilities, Boeing can also preview the latest in HPC hardware and software before adding new systems to their own data center.

When it comes to high performance computing (HPC), Doug Ball, Boeing's chief engineer for enabling technology and research, acts locally and thinks globally. And from his perspective, competition on today's global playing field has changed radically.

Marketplace pressures are becoming more intense, and accelerating the pace of design is essential in today's aerospace marketplace. Although Airbus is the only other manufacturer of commercial jetliners that seat more than 100 people, the market for short- and medium-range regional jets is becoming increasingly crowded with new entries from companies like Embraer in Brazil, Sukhoi in Russia, Mitsubishi in Japan, Bombardier in Canada, and a new regional jet from Chinese firm ACAC, the ARJ-21. "Right now these regional companies aren't competing with us directly," says Ball. "But fast-forward several years, and it may be an entirely different story."

Headquartered in Chicago, Boeing is the world's leading aerospace company and the largest manufacturer of commercial jetliners and military aircraft combined. The company employs more than 160,000 people across the United States and in 70 countries. With customers in more than 90 countries, Boeing is one of the largest U.S. exporters in terms of sales. Revenues in 2007 were nearly $66.4 billion.

Says Ball about his competitors, "The world has become a really smart place—there are highly trained, highly intelligent people everywhere, and most of them have access to high performance computing capabilities. Here in the U.S., we no longer enjoy the advantage we had in the 1950s and 1960s relative to the rest of the globe. Today our competitors are just as capable of making innovative discoveries as we are." Timing, therefore, has become critical—now the race is on to see which company will be first to come up with a particular breakthrough discovery, incorporate it into their products and services and capture the market.

Fortunately, U.S. and foreign researchers, including those in industry, have a tremendous opportunity, thanks to a now well-established Department of Energy (DOE) program—the Innovative and Novel Computational Impact on Theory and Experiment (INCITE) competition, now in its sixth year, is sponsored by the DOE's Office of Science.

Through a competitive, multi-issue, multi-industry peer-review process, the program awards significant allocations on some of the world's most powerful supercomputers to innovative, large-scale computational science projects to enable high-impact advances. Boeing is one of those awardees.
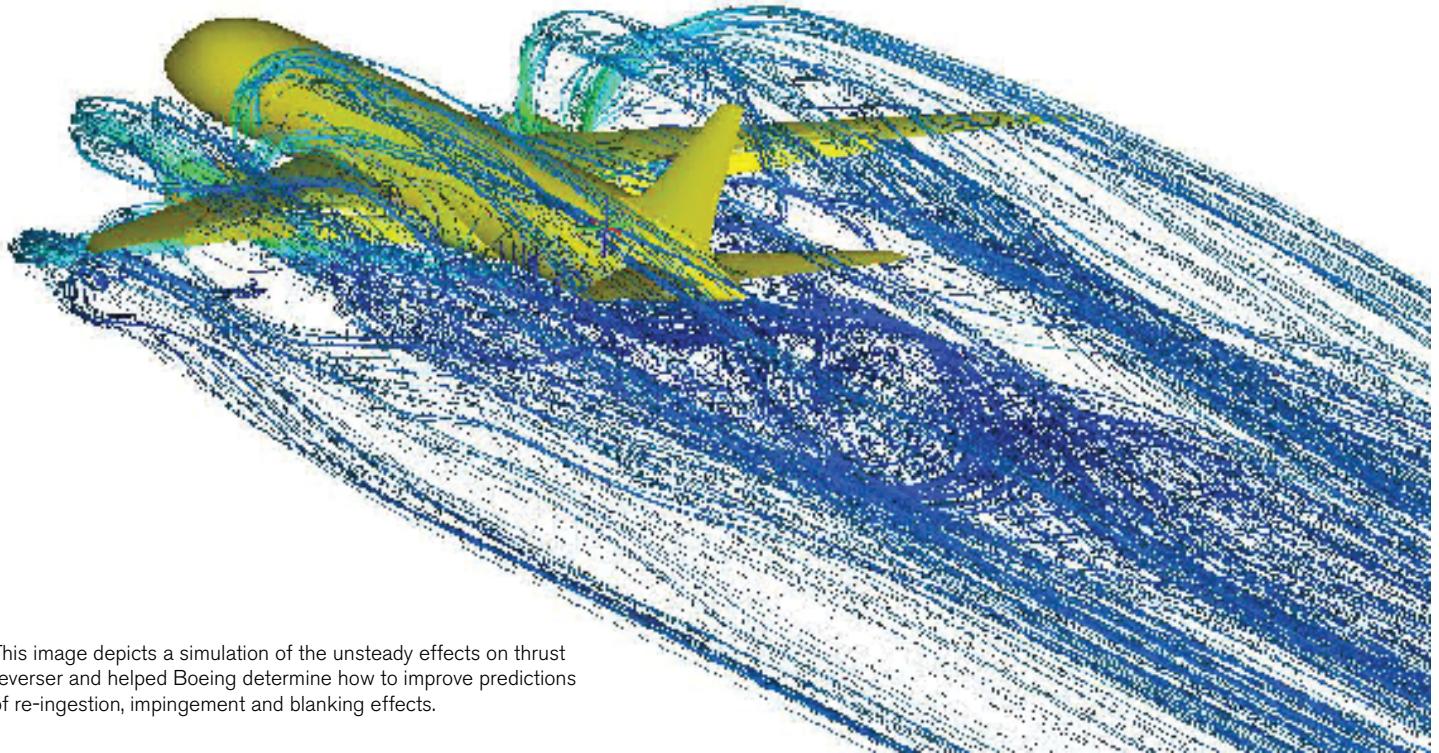
This image depicts a simulation of the unsteady effects on thrust reverser and helped Boeing determine how to improve predictions of re-ingestion, impingement and blanking effects.

Scientists and engineers in Ball's R&D group at Boeing are performing complex basic research on problems related to some of the company's most advanced commercial and military aircraft. His staff of 145 people supports aerodynamic, propulsion, fuels and acoustic technology development. Pursuant to the terms of the DOE program, research on non-proprietary projects is undertaken with the intent to publish the results in open peer-reviewed literature. The results of proprietary projects are not published, but then the work is subject to negotiated terms with DOE, which include cost recovery by DOE. Whether published or proprietary, the results of the basic research that INCITE enables ultimately provide new tools, processes and technology ideas that Boeing development groups can use to design airplanes.

Currently the R&D group is investigating ways to improve aircraft performance. They use computational modeling and simulation to explore various design options before building physical prototypes and conducting experimental testing. Working with the INCITE program and Oak Ridge National Laboratory (ORNL) plays a major role in their work.

Investigating Aeroelasticity
One of the areas Boeing researchers have modeled using ORNL's supercomputers is aeroelasticity—that is,

the effect of aerodynamic loads on airplane structures. Ball explains that when a wing is subjected to lift, loading causes the wing to deform—it tends to bend upward and twist. To get the best possible performance from the airplane, engineers use the wings aeroelasticity to obtain maximum wing loading—this provides optimal lift and reduces drag that, in turn, lowers fuel consumption. This is static aeroelasticity. The other physical condition under investigation is dynamic aeroelasticity, which occurs when the wing is subjected to sudden forces such as a wind gust. Designing the wing to handle oscillations induced by these forces makes for a smoother and safer ride.

"Of course, one way to solve the problem is to build a big, beefy, super strong wing," Ball says. "But a heavy wing is bad design—what we're really trying to do is design a wing with minimal weight that meets our design criteria. For example, one approach is to add more structure only in those places that are taking the brunt of the static and dynamic aeroelasticity forces. In addition, we are advancing the state of the art in the use of composites."

The Dreamliner® wing, the first Boeing product to make significant use of composites, is lighter and safer than its metal predecessors, and its greater efficiency results in reduced fuel consumption and emissions. Understanding how these new materials can be used in future wing design is a major goal of Ball's group.

"Composites give us a whole new degree of freedom that we don't have with aluminum structures," he explains. "The entire wing deformation process depends on how the carbon fibers are laid. By altering their patterns, we should be able to tailor the structure of the wing to put the load in the right places. This will allow us to achieve minimum weight and maximum performance."

Putting HPC to Work

Ball's research group is no stranger to HPC. They have been using the most powerful systems available during the past 30 years. Their most recent supercomputer, a vector processing system that can accommodate thousands of processors, is augmented by five Linux-based HPC clusters with a total of 792 nodes.

With the help of these supercomputers, the group uses numerical processes to investigate both the internal and external areas of the airplane. For example, they use HPC to design the airplane's shape, including the cab, wings and tail; engines and their support; fuselage closure; flap track fairings; and high lift systems. HPC capabilities are also enlisted to model the noise inside the aircraft's cabin generated by internal systems such as inlet and exhaust flow from air conditioning packs.

Although Boeing has impressive in-house supercomputing capabilities, the INCITE award provides a welcome boost to the R&D group's computational capabilities and gives researchers in the group a very valuable glimpse into future HPC hardware possibilities.

"When we made our first application for an INCITE award, the 787 was in the middle of its development and all of our in-house resources were dedicated to designing the airplane," Ball explains. "Without access to the ORNL supercomputers, our research efforts would have stalled for an unacceptably long period of time. In addition, the ORNL machines are so powerful that we were able to tackle very difficult problems that are impossible to explore with our in-house resources."

"The other major advantage of receiving the INCITE award is that the national labs like ORNL have the ability to upgrade their supercomputing resources more often than we do in industry," he continues. "This means we

have access to the latest HPC hardware and software in order to work with the latest equipment, tools and processes before purchasing new hardware for our own data center. Upgrading our in-house HPC capabilities involves major expenditures, so the ability to try before we buy is a huge plus."

HPC's Competitive Impact: Boeing Taking Off

Here's how Ball summarizes the major benefits of HPC: "It lets engineers design better airplanes with fewer resources, in less time, with far less physical simulation based on wind tunnel testing," he says. "For example, when we were designing the 767 back in the 1980s, we built and tested about 77 wings. By using supercomputers to simulate the properties of the wings on recent models such as the 787 and the 747-8, we only had to design seven wings, a tremendous savings in time and cost, especially since the price tag for wind tunnel testing has skyrocketed over the past 25 years."

Ball adds, "This is all the more impressive when you consider the fact that the new wings have been completely redesigned to take advantage of our latest research into aeroelasticity and advanced composite materials. So, while the amount of wind tunnel testing has decreased by about 50 percent, the characteristics of our current computer-based testing is dramatically different."

They are now able to look more closely at various design conditions, failure modes and loading models, and are able build a much larger database. "For example," Ball notes, "back in the days of the Boeing 707, we could handle six or seven load cases. Today we have designed thousands of load cases to simulate on the supercomputer."

Ball concludes that both his group and Boeing top management consider supercomputing and the INCITE program major strategic assets. He says, "Our work with supercomputers allows us to get a better product out the door faster, which makes us more competitive—it's as simple as that."

In Brief

Key Challenges

- Stay competitive in an increasingly aggressive and crowded marketplace

- Address complex wing design problems related to static and dynamic aeroelasticity

- Understand the problems and potentialities of incorporating advanced composite materials such as carbon fiber into aircraft design

Solutions

- Use in-house supercomputers and high performance computing clusters to investigate design solutions encompassing both the outside and inside of the aircraft

- Augment in-house capabilities by competing for INCITE awards that enable researchers access to the supercomputers at Oak Ridge National Laboratory for use in tackling the largest problems of computational modeling

- Expose researchers to emerging new supercomputing capabilities at a national laboratory

Key HPC Benefits

- Enables insight into difficult, large-scale problems that are beyond the capabilities of in-house HPC systems

- Permits researchers to validate that tools and processes that they have developed are ready to hand over to the design engineers

- Significantly reduces the need for costly physical prototyping and wind tunnel testing

- Helps speed airplane design, lowering cost and spurring enhanced competitiveness

Web Site

- www.boeing.com
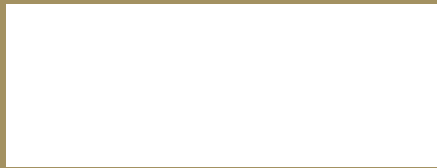
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